DOE/OR/07-1916&D1

Seismic Issues for Consideration in Site Selection and Design of a Potential On-Site Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) Waste Disposal Facility at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky

Cleared for Public Release

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contributed to the preparation of this document and should not be considered an eligible contractor for its review.

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Seismic Issues for Consideration in Site Selection and Design of a Potential On-Site Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) Waste Disposal Facility at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky

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Prepared for the
U.S. Department of Energy
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by
Bechtel Jacobs Company LLC
managing the
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Paducah Gaseous Diffusion Plant

for the
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ACRONYMS AND ABBREVIATIONS

ARAR	applicable or relevant and appropriate requirement
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	*Code of Federal Regulations*
COE	U.S. Army Corps of Engineers
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
fps	feet per second
g	the acceleration resulting from the Earth's gravitational field
KAR	Kentucky Administrative Regulations
LLW	low-level (radioactive) waste
M_L	magnitude
MSWLF	municipal solid waste landfill
NMSZ	New Madrid Seismic Zone
NPH	natural phenomena hazards
PGDP	Paducah Gaseous Diffusion Plant
RCRA	Resource Conservation and Recovery Act
SSC	structures, systems, and components
TBC	to be considered
TSCA	Toxic Substances Control Act
TSD	treatment, storage, and disposal
USGS	U.S. Geological Survey
WES	Waterway Experimental Station

1. INTRODUCTION AND OVERVIEW OF POTENTIAL DISPOSAL FACILITY

The U.S. Department of Energy (DOE) is evaluating waste disposal alternatives at the Paducah Gaseous Diffusion Plant (PGDP) to handle remediation and decontamination and decommissioning (D&D) wastes from cleanup efforts at the site.

Approximately 458,730 m^3 (600,000 yd^3) of waste are expected to be generated during near-term environmental cleanup at the PGDP. Future D&D activities may result in an additional 1,910,000 m^3 (2,500,000 yd^3) of waste. The wastes are regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). One option DOE is considering for management of these wastes is the construction and operation of an on-site CERCLA waste disposal facility at PGDP. Based on the expected volumes, an on-site CERCLA waste disposal facility would have to accommodate approximately 2,400,00 m^3 (3,100,000 yd^3) of waste. Such a disposal facility would be sited and designed in accordance with applicable technical requirements and would be expected to receive wastes subject to regulation under the Resource Conservation and Recovery Act (RCRA) and the Toxic Substances Control Act (TSCA) as well as low-level (radioactive) waste (LLW) and mixed waste requirements.

Based on DOE experience at other sites and knowledge of the PGDP site conditions, the depth to groundwater probably would not support construction of below-grade disposal cells. Therefore, a potential on-site PGDP waste disposal facility likely would be composed of above-grade disposal cells underlain by a leachate collection system, laterally surrounded by clean fill dikes, and covered by a multilayer cap. These design features would provide for stable containment and protect against erosion and inadvertent intrusion by humans or animals. Based on estimated volumes, the total footprint of the disposal cells and support facilities would be approximately 44.52 ha (110 acres).

Other wastes generated at PGDP outside the near-term environmental cleanup and future D&D activity programs mentioned above will not be included in the waste stream planned for disposal in the potential on-site CERCLA waste disposal facility. These other wastes include legacy (stored) and operations wastes, DOE wastes generated outside Kentucky, waste forms prohibited from shallow land disposal (such as liquids), waste types prohibited by regulation (such as transuranic wastes), and all other non-CERCLA wastes.

An Initial Assessment of this concept recently was conducted. The potential seismic activity in the PGDP area presents a key siting/design consideration for such a facility (DOE 2000). The purpose of this paper is to expand on the Initial Assessment and to specifically address the seismic issues relating to siting, design, construction, operation, and closure of a CERCLA waste disposal facility at the PGDP. This paper represents a review of available, relevant documents. Additional information, as appropriate, will be collected, reviewed, and incorporated into the siting study and remedial investigation/feasibility study reports in preparation. This paper is organized as follows.

- Section 2.0 reviews available documentation relating to the geologic and seismological setting of the PGDP. The purpose is to identify geologic features or unstable ground that would be considered constraints on the siting of a potential CERCLA waste disposal facility.

- Section 3.0 reviews various state and federal regulations used to identify those requirements relating to seismicity for the siting and design of a waste disposal facility. The purpose of the review is to develop some proposed siting and design criteria.

- Section 4.0 summarizes the evolution of seismic design at PGDP, reviews the seismic design basis for other DOE CERCLA waste disposal facilities, and reviews the performance of landfills that have been subjected to large seismic events.

- Section 5.0 assesses the potential for seismic concerns to be an obstacle to the construction of an on-site CERCLA waste disposal facility.

2. GEOLOGIC AND SEISMOLOGICAL SETTING

Several factors influence the performance of a facility in response to a seismic event. These factors include:

- Location of the facility relative to the epicenter of the seismic event,

- Magnitude of the seismic event,

- Ability of the geologic profile to transmit energy of the seismic event from the epicenter to the facility,

- Competency of foundation soils at the facility, and

- Ability of the facility to absorb energy from the seismic event without compromising safe operations or performance.

All of the above factors must be considered in the determination of a site-specific ground motion for the design at a given facility. The following sections discuss the PGDP with respect to the first four factors. The last factor will be dependent upon the actual design and construction of a potential facility.

2.1 LOCATION

The PGDP is located in northwestern Kentucky, close to the Ohio River and just to the west of Paducah, Kentucky. Seismic activity in the area primarily is the result of continental compression that is reactivating the New Madrid Seismic Zone (NMSZ), 100 km (62 miles) to the west of the PGDP. The NMSZ lies in the five-state area of Missouri, Arkansas, Tennessee, Kentucky, and Illinois. Four or five major earthquakes are believed to have occurred in the NMSZ in late 1811 and early 1812 (Nuttli 1982). The most significant earthquakes during this period were estimated to have a magnitude (M_L) greater than 8.0 (LMES 1995). Much of the region, except for river towns, was uninhabited at the time of these extremely large events, so accounts of damage and details of near-field ground response and failure were few. Two studies conducted after the turn of the century documented eyewitness accounts (Berry 1908) and remnants of ground failure (Fuller 1912). Street and Nuttli (1984) revisited these two early studies, adding more recent information. Obermeier (1984) focused on liquefaction and ground failures.

2.2 ATTENUATION

The ability of the geologic profile to transmit (attenuate) the energy of an earthquake from the epicenter to a facility is a function of the competency of the foundation rock and soil. In addition to the distance a facility is from the epicenter of a seismic event, the existence of faults in bedrock and different consistencies of soil between the seismic epicenter and the facility also will modify the energy profile

reaching the facility. As an example, the extent to which a similar size earthquake will be felt in the central part of the United States is much greater than in California because of the above factors.

2.2.1 Stratigraphy

The PGDP is located near the northern tip of the Mississippi Embayment of the Coastal Plain physiographic province (see Fig. 1). The area is bounded on the north and east by the Highland Rim portion of the Interior Low Plateau physiographic province, an area of low plateaus on stratified sedimentary rock. A wedge of Cretaceous- through Quaternary-Period sediments fills the Mississippi Embayment. This represents materials that were deposited within the last approximately 125 million years. Approximately 104 m (340 ft) of unconsolidated sediments, resting on a bedrock of Mississippian-age carbonates (deposited between 310 million to 345 million years ago), underlie the PGDP. The wedge of sediments thins rapidly to the north and extends approximately 15 km (9 miles) north of the Ohio River into southern Illinois. Paleozoic bedrock exposures (deposited between 225 million and 510 million years ago) occur north of the Mississippi Embayment sediments.

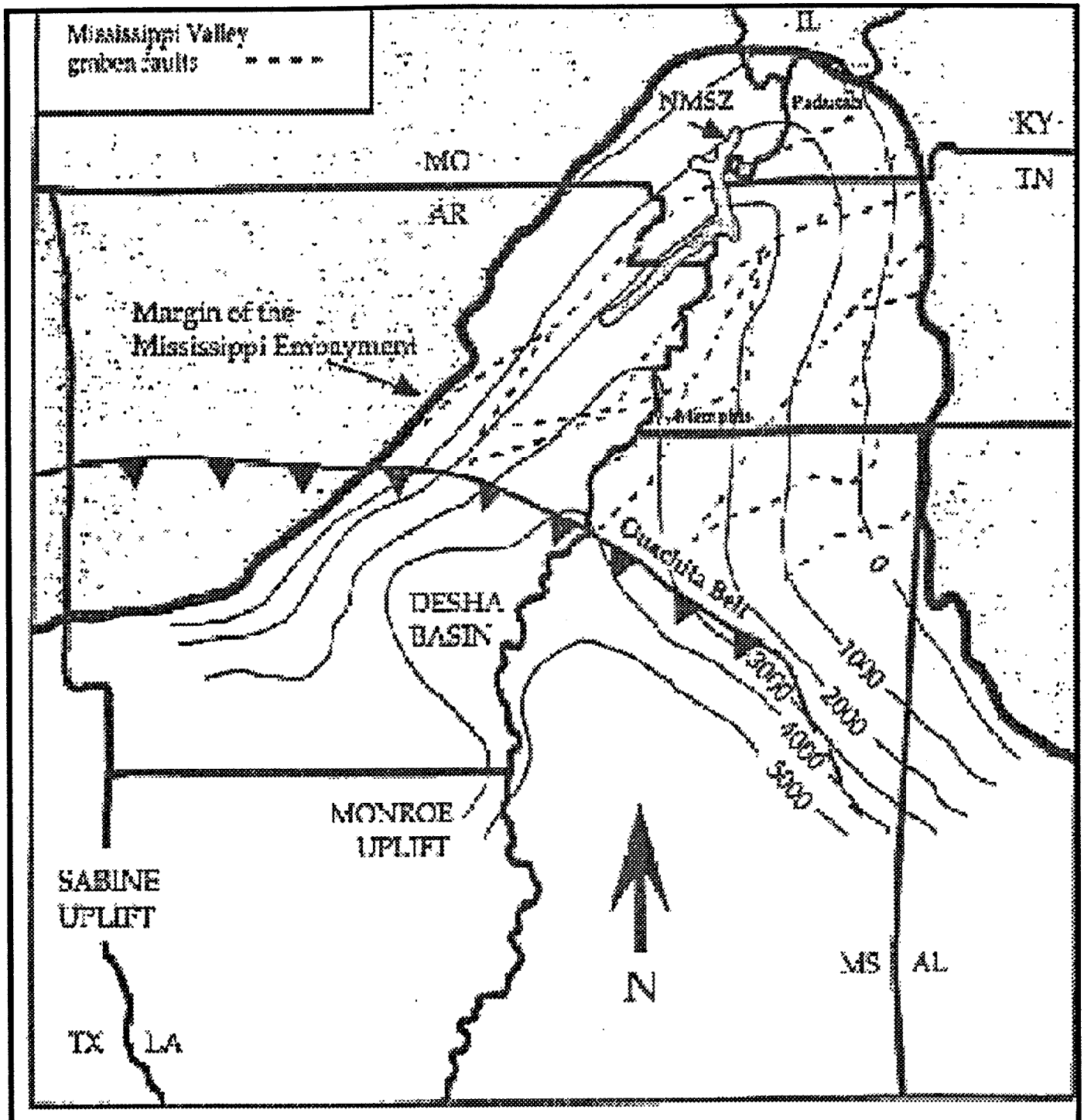
The Mississippi Embayment has undergone several cycles of uplifting with consequent erosion and downwarping with consequent deposition (Sykora and Yule 1996). Tertiary-age deposits (1 million to 63 million years) were placed in marine environments. Pleistocene-age continental deposits (less than 1 million years) were deposited in fresh-water environments on erosional surfaces of Tertiary-age deposits. According to ERCE (1990) these deposits may represent part of a large alluvial fan and may consist partly of reworked glacial outwash. Based on the history of deposition and erosion, soil deposits at PGDP are expected to be normally consolidated or possibly slightly overconsolidated.

The local soil profile generally can be described as consisting of a surficial veneer of loess, alluvium, and continental deposits of gravel, sand, silt, and clay, overlying Tertiary-age deposits of predominantly clay interbedded with sands and silts, and occasionally a "rubble zone." Fill is expected at the ground surface in isolated locations. Hard limestone bedrock underlies the entire site below a depth of approximately 104 m (340 feet). The soil deposits and limestone dip gently downward to the south (ERCE 1990). The shallow soils are generally unsaturated. Street and Langston (1998) reported that shear wave velocities measured in loess range from 500 to 770 fps, from 800 to 1500 fps in the alluvium, and between 1000 and 1550 fps in the Tertiary deposits. Figure 2 is a schematic of the stratigraphic relationship of these deposits at the PGDP.

2.2.2 Faults

Geologic maps of the PGDP area delineate few faults and even these may be attributed to non-tectonic origins. The closest mapped faults in Kentucky are located approximately 6.5 km (4 miles) to the east and 8 km (5 miles) to the northwest of PGDP (Olive 1980). Several faults of the southern Illinois Flourspar Area Fault Complex trend toward the PGDP. Researchers have documented deformation in the Metropolis Gravel, a unit that likely is equivalent to the Pleistocene sediments that underlie the PGDP, among these faults (Nelson et al. 1997).

The Kentucky Geological Survey has used several techniques to define the geologic structure of western Kentucky, including the PGDP area. Based on imagery from side-looking air-borne radar, Drahovzal and Hendricks postulate two regional northeast–southwest lineaments extending through the PGDP security fenced area, as well as three other nearby lineaments within or adjacent to the DOE reservation (Drahovzal and Hendricks 1996) (Fig. 3). These surface lineaments closely correspond to regional lineaments in the top-of-basement map for the Paducah area, which may be related to faulting.



SOURCE:
RISK ENGINEERING 1999

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PADUCAH GASEOUS DIFFUSION PLANT

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BECHTEL JACOBS COMPANY, LLC
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Figure 1. The New Madrid Seismic Zone within the Upper Mississippi Embayment

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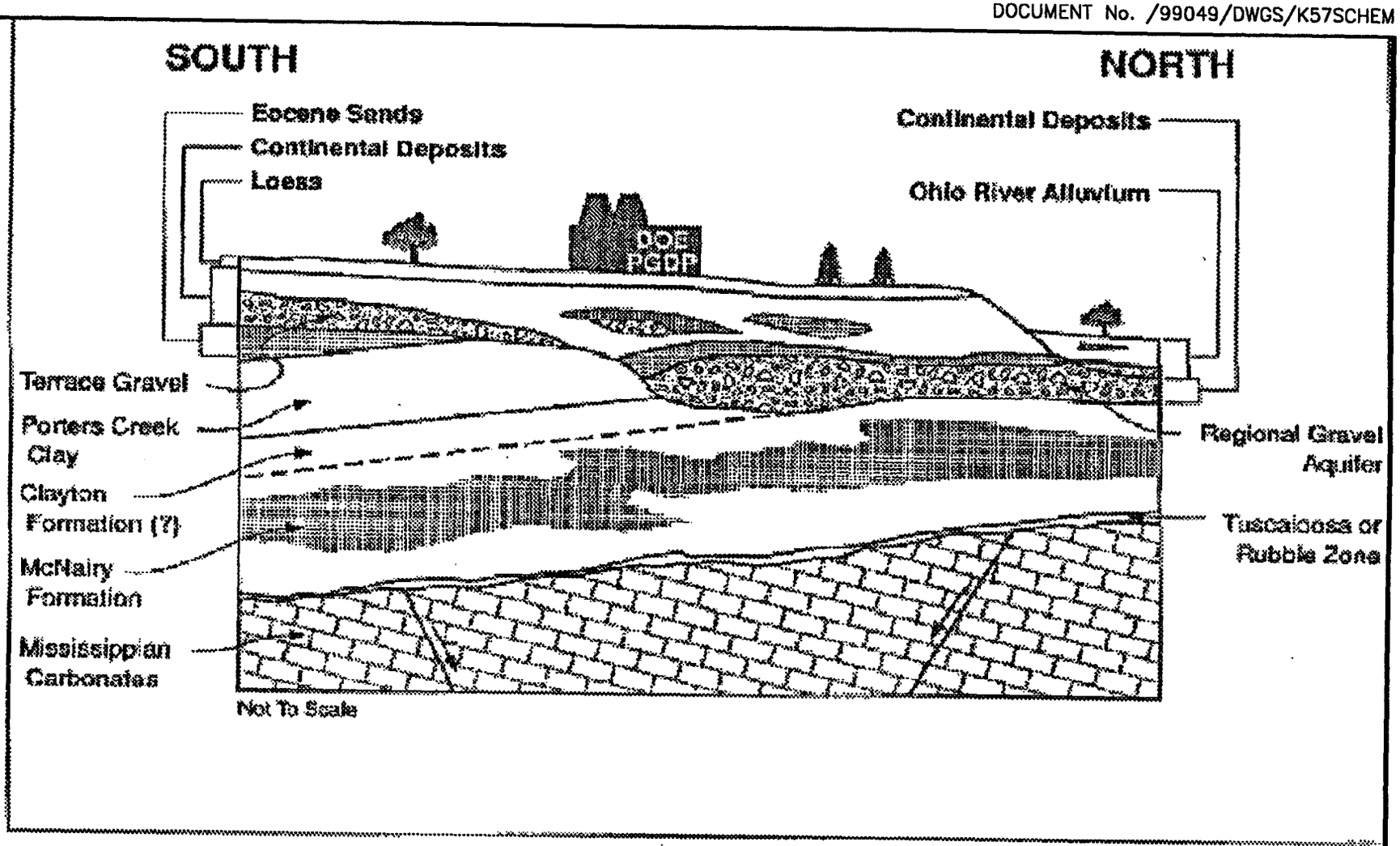

SOURCE:
SAIC 1993

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Figure 2. Schematic north-south section showing regional stratigraphic relationships at PGDP

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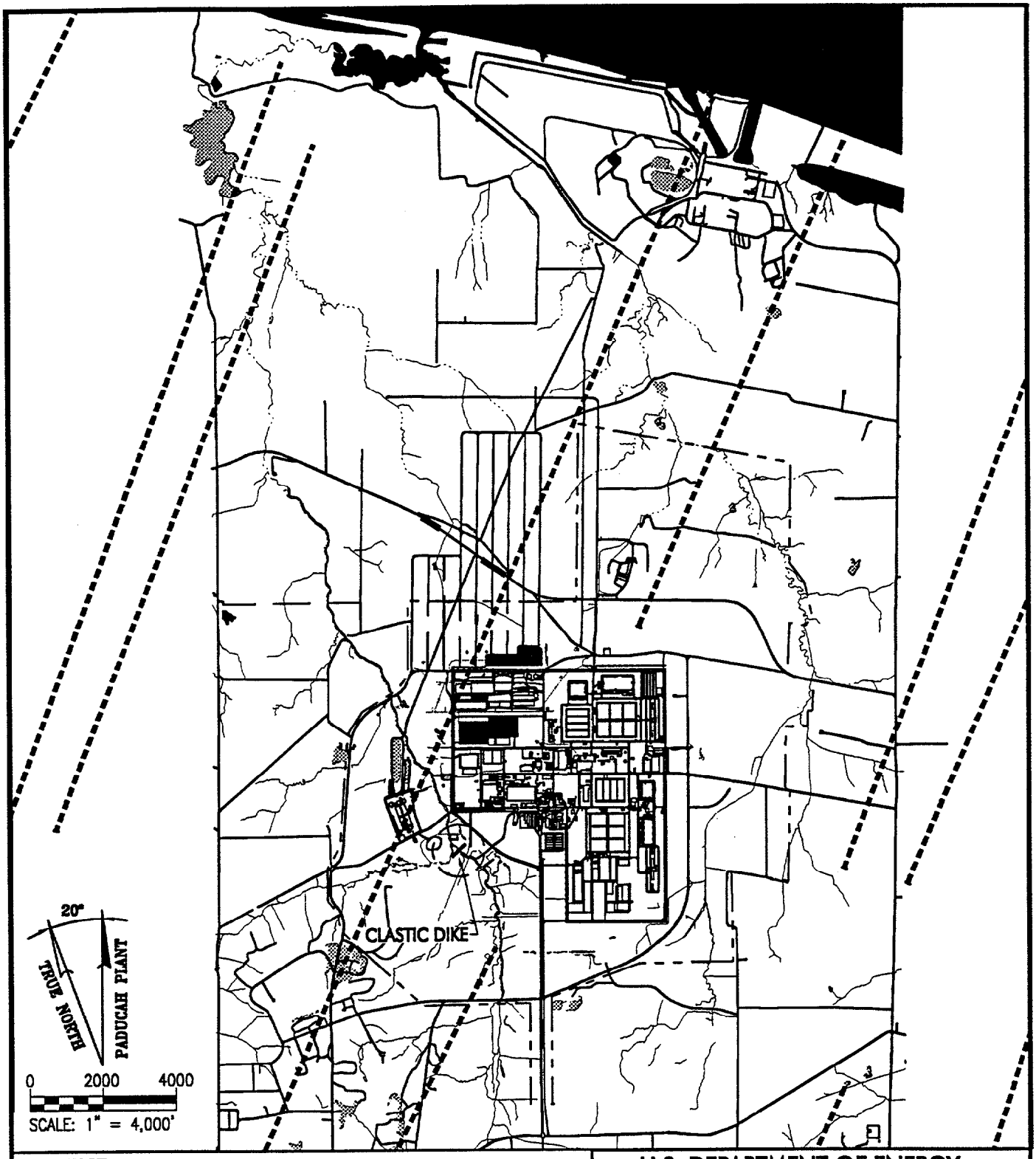

LEGEND:

DOE BOUNDARY

.. LINEAMENT FEATURE FROM DRAHOVZAL & HENDRICKS (1996)

POTENTIAL FAULT AS DEFINED BY STREET & LANGSTON (1998)

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Figure 3. Potential faults and lineaments in the vicinity of the Paducah Gaseous Diffusion Plant.

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Street and Langston present the interpretation of seismic profiles within the PGDP reservation. Seismic data define six main transects located east and north of the main plant. In the report, researchers identify three seismic anomalies that they attribute to faulting (Street and Langston 1998).

- A structural depression on seismic reflectors to the north–northwest of the PGDP suggests the presence of a large graben, progressing upward from bedrock into the lower Continental Deposits (Pleistocene-Epoch–deposited 10 to 12 thousand through 2.5 million years ago)—approximately 1 km (0.6 mile) wide in the lower Continental Deposits—that trends northeast–southwest.

- Three seismic lines on the north side of the plant secured area indicate a northeast–southwest trending zone of displacement in the base of the lower Continental Deposits, with the down-thrown block to the northeast.

- Two seismic lines on the east side of the plant indicate a northeast–southwest trending structure that may be the buried south bank of the ancestral Tennessee River, which flowed through the area during the Pleistocene Epoch.

These seismic anomalies appear to indicate that any faults and lineaments at the PGDP site are of Pleistocene age. This information will be reviewed during the siting study. However, to date, no clear evidence of Holocene Epoch (within last 10 to 12 thousand years)-faulting exists at the PGDP. Surficial geologic maps and reconnaissance of area creek banks have not found indications of faulting within the shallowest sediments and soils that represent the most recent time period. It may be possible that minor faulting exists within the Holocene Epoch sediments of the region, but that the effects are masked by active erosion and deposition and by vegetation.

2.3 FOUNDATION COMPETENCY

The competency of local soil materials during an earthquake usually is related to foundation stability, soil liquefaction, and dynamic settlement. Foundation stability is related to the capacity of the foundation materials to support the facility without a slope or bearing type failure, which is directly related to the material properties and loads being applied. Material properties and loads being applied are site-specific parameters that will be investigated and evaluated during the design process.

Soil liquefaction and dynamic settlement evaluations also will be performed during the site-specific investigations. However, previous studies of soil liquefaction have been performed with both regional and local focus.

During strong earthquake shaking, loose, saturated, cohesionless soil deposits may experience a sudden loss of strength and stiffness, sometimes resulting in large, permanent displacements of the ground. This phenomenon is called soil liquefaction. Liquefaction beneath and in the vicinity of a waste disposal facility can have severe consequences with respect to the integrity of the facility containment system. Localized bearing capacity failures, lateral spreading, and excessive settlements resulting from liquefaction may damage landfill liner and cover systems. Liquefaction-associated lateral spreading and flow failures also can affect the global stability of the landfill. Therefore, a liquefaction potential assessment is a key element in the seismic design of landfills (EPA 1995).

Several investigators have searched for paleoliquefaction evidence of prehistoric earthquakes similar to the 1811–1812 events. Munson et al. (1997), Obermeier (1996), and McNulty and Obermeier (1999) report on extensive field investigations in southern Illinois and southern Indiana. The banks of the Ohio River have been searched for evidence of large prehistoric earthquakes from approximately 25 km

(15.5 miles) west of the PGDP to the river's confluence with the Wabash River, approximately 100 km (62 miles) northeast of PGDP. Three locales, where "young" liquefaction features were noted, were discovered along this stretch of the Ohio River. McNulty and Obermeier (1999) attribute these features to the 1811–1812 New Madrid events. Farther to the northeast, there is a preponderance of large [>0.50 m- (> 1.6 ft-) wide] liquefaction features that date back to approximately 6100 years before present. Based on the size of sand dikes and distribution of liquefaction features, a movement magnitude (M_L) of 7.5 is suggested for the prehistoric event. The epicenter would lie approximately 200 km (124 miles) northeast of PGDP.

Available information suggests that no liquefaction or ground failure occurred in the upland surface at the present PGDP during the 1811–1812 earthquakes. While liquefaction occurred in younger alluvial deposits farther away from the NMSZ, the only reported failures in the upland surface during the these earthquakes were slope failures on bluffs of the Mississippi River near Wickliffe, Kentucky (Jibson and Keefer 1984). These reported failures are significantly closer to the NMSZ and the 1811–1812 epicenters than the PGDP. The Pleistocene-age and older deposits at greater distances, like at PGDP, performed well (Sykora and Yule 1996). To date, no evidence of large paleoseismic events has been discovered near PGDP. A local search focused along the Ohio River adjacent to the PGDP reports no evidence of paleoliquefaction (Risk Engineering 1997).

Site-specific soil modeling studies performed for PGDP by the U.S. Army Corps of Engineers (COE) Engineer Waterway Experimental Station (WES) assessed the potential for liquefaction and earthquake-induced settlement using a site-response analysis (Sykora and Davis 1993). The input earthquake parameters were defined based on probabilistic methods of hazards analysis performed by Risk Engineering (1993) using an extended source model for the NMSZ, detailed subsurface geotechnical engineering investigations (ERCE 1990), and geophysical measurements such as shear wave velocities (Automated Science Group 1991). The peak acceleration used in these analyses was 0.30 g, corresponding to a magnitude 7.3 earthquake at an epicentral distance of 50 km (31 miles). When the analysis was performed, this magnitude/distance scenario was used to represent the 1000-year event. The results of dynamic modeling indicated that liquefaction should not occur in the event of this earthquake scenario at the PGDP.

Several factors contribute to the low potential for liquefaction. Foremost is the location of PGDP on an upland surface above the alluvial valley of the Ohio River. While saturation of loose soils typically increases the potential for liquefaction, the near-surface loose soils at PGDP typically are dry. The deeper saturated granular materials are older and denser, resulting in more stable conditions under seismic loading.

The WES study did find that some excess pore water pressure could occur at depth in isolated pockets of sands and gravels and predicted that earthquake-induced settlement theoretically could occur. The maximum calculated settlement was predicted to be less than 2.5 cm (1 inch) within the deep deposits. The effect at the surface would be even smaller.

3. REGULATORY CONSIDERATIONS

Appendices A, B, and C present the various state and federal regulations related to seismic issues that are interpreted to be either potentially applicable requirements or To Be Considered (TBC) guidance for the siting and design of an on-site CERCLA waste disposal facility at the PGDP. As detailed in these appendices, the regulations address a variety of potential waste streams that could include Subtitle D (municipal waste), Subtitle C (hazardous waste), TSCA, LLW, and mixed wastes. Table 1 lists the type of waste stream (i.e., solid, hazardous, etc.), identifies the pertinent regulation, and summarizes the seismic

requirement. As shown in Table 1, there is a significant degree of overlap among the various regulations for the different types of waste.

3.1 COMMONWEALTH OF KENTUCKY REGULATIONS

Appendix A identifies Commonwealth of Kentucky regulations that potentially should be considered during siting and design activities for a CERCLA waste disposal facility at the PGDP. Regulations that are cited in Appendix A include licensing requirements for land disposal of radioactive waste (401 KAR 38), substantive criteria for municipal solid waste landfills (401 KAR 48), and substantive standards for owners/operators of hazardous waste treatment, storage, and disposal (TSD) facilities (401 KAR 34). The state regulations are consistent with the corresponding federal regulations.

3.2 FEDERAL (NON-DOE) REGULATIONS

Appendix B identifies federal regulations that potentially should be considered during siting and design activities for a CERCLA waste disposal facility at the PGDP. Regulations that are cited in Appendix B include substantive licensing requirements for land disposal of radioactive waste (10 *CFR* 61.50), substantive criteria for municipal solid waste landfills (40 *CFR* 258.13 and 258.14), and substantive standards for owners/operators of hazardous waste TSD facilities (40 *CFR* 264.14). A U.S. Environmental Protection Agency (EPA) guidance document titled *RCRA Subtitle D (258) Seismic Design guidance for Municipal Solid Waste Landfill Facilities* (EPA 1995) is also identified for informational/reference purposes.

3.3 DOE ORDERS AND STANDARDS

Appendix C identifies DOE Orders and Standards that potentially should be considered during siting and design activities for a CERCLA waste disposal facility at the PGDP. DOE Order 420.1 includes objectives to ensure that DOE facilities are designed, constructed, and operated to protect the general public, workers, and environment from the impact of natural phenomena hazards, including seismic events. Appendix C identifies the sections of the Order that are pertinent to design requirements for seismic events. DOE also has developed technical standards associated with natural phenomena hazards. These standards are identified in Appendix C with the pertinent seismic requirements identified.

3.4 PROPOSED SEISMIC SITE SELECTION CRITERIA

Review of the potentially applicable requirements and TBCs presented in Appendices A, B, and C forms the basis for the development of two proposed seismic-related site selection criteria that could be used to identify suitable sites at the PGDP and to aid in facility design. Each of the proposed criterions is presented below, along with a brief discussion of technical considerations.

Table 1. Summary of potentially applicable requirements based on waste type

Regulation/ARAR	Subtitle D (Municipal Landfill)	Subtitle C (Hazardous Waste)	TSCA	LLW	Mixed Waste	Requirement Summary
401 KAR 48:050	X					screen for faults in siting
401 KAR 48:070	X					design for max. horizontal acceleration
40 *CFR* 258.13	X					screen for faults in siting
40 *CFR* 258.14	X					design for max. horizontal acceleration
401 KAR 34:020		X			X	200 ft setback from fault with movement in Holocene time
401 KAR 34:340		X			X	county location restriction
401 KAR 38:090		X			X	requirements for documentation of meeting 200 ft setback from faults
40 *CFR* 264.18		X			X	200 ft from fault movement in Holocene time
40 *CFR* 270.14		X			X	KY not on list, refer to 401 KAR 38:090
40 *CFR* 761.75		X	X			no requirements with respect to siting or design for seismic issues
902 KAR 100:022				X	X	screen for faults in siting
10 *CFR* 61.50				X	X	screen for faults in siting
DOE O 420.1						
Section 4.4	X	X	X	X	X	requires consideration of seismic activity
Section 4.4.1	X	X	X	X	X	safety analysis must include effects of seismic events
Section 4.4.2	X	X	X	X	X	demonstrate confinement of hazardous material
Section 4.4.4	X	X	X	X	X	assessment of seismic hazard must be considered in siting facility
Section 4.4.5	X	X	X	X	X	must have instrumentation in place before seismic event
Section 4.4.6	X	X	X	X	X	establish procedures in place in case of seismic event
DOE-STD-1020-94	X	X	X	X	X	requires consideration of seismic activity
DOE-STD-1021-93	X	X	X	X	X	establishes procedure for selection of performance categories
DOE-STD-1022	X	X	X	X	X	identifies requirements for site characterization
DOE-STD-1023	X	X	X	X	X	establishes procedure for determining seismic hazard for site
DOE-STD-1024-92	X	X	X	X	X	establishes procedure for developing seismic hazard curves for site
ES-CNPE-95/2	X	X	X	X	X	developed seismic hazard criteria for facility

ARAR = applicable or relevant and appropriate requirement
CFR= Code of Federal Regulations
DOE = U.S. Department of Energy
KAR = Kentucky Administration Regulations
LLW = low-level (radioactive) waste
TSCA = Toxic Substances Control Act of 1976

3.4.1 Seismic Siting Criterion 1

Areas will be avoided that are within 61 m (200 ft) of a fault that has displacement in Holocene time (within the last 10,000 to 12,000 years).

Technical Basis

This is the primary geological/seismological siting criterion required by the regulations. Locating a disposal facility in close proximity to a fault that has moved during the recent geologic past (and would, therefore, be expected to move in the future) has inherent dangers including the following:

- fault movement causing displacement of facility structures;
- fault movement resulting in vibratory ground motion that can cause damage; and
- ground shaking that can cause ground failures such as slope failure, settlement, and liquefaction.

For sites that lie within 914 m (3000 ft) of (1) a fault that has had displacement in Holocene time or (2) lineations that suggest the presence of a fault with displacement of Holocene time, field studies will be conducted to appropriately assure that the site meets the 61-m (200-ft) setback limitation. Lineations are visual indications that show up in some manner, such as lines on an air photo or in a remote sensing survey, that may or may not indicate the presence of a fault.

3.4.2 Seismic Siting Criterion 2

Areas will be avoided that are susceptible to slope failure, excessive settlement, or liquefaction.

Technical Basis

This criterion is based on regulatory requirements that state: "Areas will be avoided where tectonic activity such as folding, faulting, or seismic activity occur with a frequency and extent to significantly affect the ability of the disposal facility to meet the performance objectives or may preclude defensible modeling and prediction of long-term impacts." Locating a disposal facility where the rate of tectonic activity is sufficiently high to preclude modeling or to adversely impact facility performance has the same inherent dangers noted for siting Criterion 1.

3.5 PROPOSED SEISMIC DESIGN CRITERIA

Review of the potentially applicable requirements and TBCs presented in Appendices A, B, and C has led to the development of three proposed seismic-related design criteria. Each of the proposed criterions is presented below along with a brief discussion of technical considerations.

3.5.1 Seismic Design Criterion 1

The facility will be designed to withstand ground shaking caused by infrequent large earthquakes.

Technical Basis

Regulations require that containment systems be designed to resist the levels of ground shaking of an earthquake with a return period of approximately 2500 years. Such an event has only a 10% probability of occurring during the next 250 years and is associated with a peak horizontal ground motion equal to 40% of gravity (0.40 g) (see Fig. 4) (Algermissen et al. 1991). The peak horizontal ground motion is the

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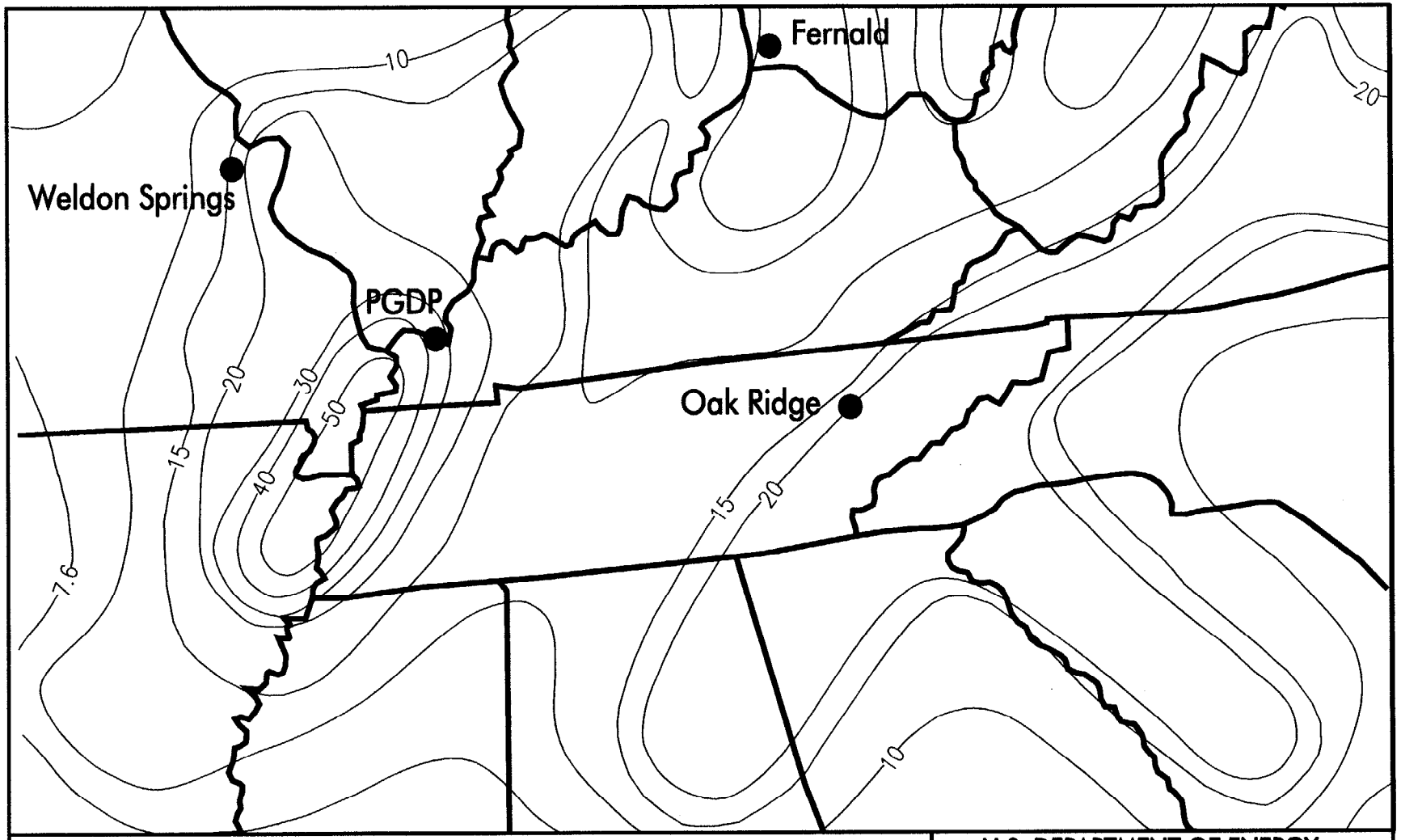

NOTE:
ACCELERATIONS ARE EXPRESSED IN PERCENT OF GRAVITY.

SOURCE:
Algermissen et al. 1991

NOT TO SCALE

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Figure 4. U.S. Geologic Survey map of maximum horizontal accelerations. (90% probability of not being exceeded in 250 years.)

Figure No. 4
DATE 11-08-00

percentage of gravity felt by a structure feature in the horizontal direction during an earthquake. It should be noted that an event with a 10% probability of being exceeded during the next 250 years is equivalent to an event having a 90% probability of not being exceeded during the next 250 years.

3.5.2 Seismic Design Criterion 2

The facility shall address seismic hazards consistent with DOE orders and standards.

Technical Basis

A seismic hazard study developed site-specific criteria for the PGDP (LMES 1995). Table 2 summarizes the result of the study. The Performance Category is a classification system established by DOE to specify the level of seismic design required for a given structure or feature based on the seismic hazard risk for that structure or feature. The performance category has a range from 0 (lowest) to 3 (highest) representing the hazard risk to the public's health and safety for a given structure. While all Performance Category 3 requirements are not directly applicable to a potential CERCLA waste disposal facility, the associated levels of horizontal and vertical ground motions would be incorporated into an eventual design. Although Seismic Design Criterion 2 appears to be a lesser design requirement than Criterion 1, it is a valid criterion, because it represents the basis for the design of structures or features at DOE facilities and provides constraints on vertical ground motions.

Table 2. Seismic hazard criteria at the Paducah reservation

		Mean Peak Ground Acceleration (g)	
Performance Category	Return Period (years)	Horizontal	Vertical
0	0	0.00	0.00
1	500	0.20	0.13
2	1000	0.25	0.17
3	2000	0.35	0.24

3.5.3 Seismic Design Criterion 3

All containment systems will be designed to withstand predicted ground displacement resulting from seismically induced liquefaction, slope failure, or settlement.

Technical Basis

In general, landfill containment systems have been shown to be flexible and capable of accepting some deformation. Slope failure, either above grade or in the foundation, or foundation failures, such as soil liquefaction, could cause significant deformations leading to a loss of containment of the waste in the facility. Therefore, foundation conditions and component properties of the facility will be considered in its analysis and design.

4. EVOLUTION OF SEISMIC DESIGN CONSIDERATIONS AT PGDP

Seismic design considerations at the PGDP have evolved from the original plant design, to the seismic evaluations performed for the Safety Analysis Report (LMES 1997a), and more recent evaluations and designs conducted to address revised DOE requirements.

4.1 ORIGINAL SEISMIC DESIGN

No specific seismic design calculations were performed to support the initial PGDP design. As was common practice during the 1940s and 1950s, it was concluded that, in the eastern United States, wind-load criteria generally provided enough resistance to handle potential seismic loading of buildings (Hunt et al. 1990).

4.2 1960s AND 1970s

Based on advances during the 1960s and 1970s, revisions were made to seismic zonation maps and building codes (ICBO 1970). The impact is mentioned in the *Recommended Seismic Hazard Levels for the Oak Ridge, Tennessee; Paducah, Kentucky; Fernald, Ohio; and Portsmouth, Ohio, Department of Energy Reservations*, K/BD-1025/R1, December 1982 (Beavers et al. 1982). This report selected a peak ground acceleration of 0.18 g for PGDP facilities. This earthquake level was based on selecting a value having a 90% probability of not being exceeded during the assumed 25 years remaining lifetime of the facility. This corresponds to an earthquake with a return period of approximately 250 years.

4.3 1980s

During the 1980s, site-specific seismic hazard studies were performed using updated methodologies. As a result of the proximity of the PGDP to the NMSZ, these new studies predicted a peak ground acceleration of 0.25 to 0.30 g for an earthquake with a return period of 1000 years (Hunt et al. 1990).

4.4 1990s

In 1993, the COE's WES performed a site-specific response study for the PGDP (Sykora and Davies 1993). Three earthquake events were developed using probabilistic methods. The peak rock outcrop ground motions were 0.19 g, 0.27 g, and 0.63 g for the 500-, 1000-, and 5000-year events, respectively. Because a thick column of sediments is present at PGDP, the local soil column was modeled using the SHAKE computer program, and resulting free field motions were calculated to be 0.20 g, 0.27 g, and 0.36 g for the 500-, 1000-, and 5000-year events, respectively.

In 1995, a report (LMES 1995) was prepared in response to DOE Orders 6430.1.A and 5480.28. The peak horizontal ground surface accelerations were calculated as 0.20 g, 0.25 g, and 0.35 g for the 500-, 1000-, and 2000-year earthquakes, respectively.

An updated probabilistic seismic hazard analysis was performed for the PGDP (Risk Engineering 1999) that reflected the current state of knowledge on the recurrence-frequency and characteristics of earthquakes in the New Madrid Seismic Zone and the Wabash Valley Seismic Zone. Based on this study, the peak horizontal ground acceleration for an earthquake with a return period of 2500 years was 0.4 g. This agrees with the current regulatory requirements.

4.5 RECENT SEISMIC UPGRADES

Executive Order 12941, *Seismic Safety of Existing Federally Owned or Leased Buildings,* was signed December 1, 1994. This order required federal agencies to develop an inventory of owned or leased buildings and estimate the costs of mitigating unacceptable risks. *Implementation of Executive Order*

12941 at the Paducah Gaseous Diffusion Plant, November 1997, documents those evaluations at the PGDP (LMES 1997b). Section 2.1 of that report indicates that all buildings were assigned the seismicity category of "Moderate," and the buildings were evaluated against an "Evaluation Basis Earthquake" with a return period of 250 years and an associated peak ground acceleration of 0.15 g. As a result of this study, the structural integrity of 11 buildings at the PGDP has been upgraded to withstand potential seismic events.

A seismic hazard criteria has been developed specifically for the PGDP. A report by Lockheed Martin Energy Systems, Inc. (LMES 1995) presents current seismic hazard curves and criteria based on state-of-the-art seismic hazard assessments that are in compliance with DOE Orders and standards. This information for the Paducah reservation is summarized in Table 2.

4.6 C-746-U LANDFILL

In 1994, a technical application (DOE 1994) was submitted to the Commonwealth of Kentucky for construction of a solid waste landfill. Construction of the C-746-U Solid Waste Landfill was completed in 1996. Supporting studies conclude that the site is located within a seismic impact zone as defined by 401 KAR 48.050 and 40 *CFR* 258.14. The Commonwealth and federal regulations stipulate that the horizontal acceleration to be used in seismic analysis shall correspond to a bedrock acceleration that has a 10% probability of being exceeded in 250 years (which corresponds to an earthquake that will occur once in 2500 years), or the maximum expected horizontal acceleration based on a site-specific seismic risk assessment. This facility was designed to a peak acceleration of 0.40 g, corresponding to a bedrock acceleration that has a 10% probability of being exceeded in 250 years. A subsequent study also was conducted in 1995 to ensure that the underlying soil layers would be able to support the landfill during the design earthquake (Hodges 1995).

This level of ground motion is consistent with the design criteria proposed for the potential on-site CERCLA waste disposal facility.

4.7 OTHER DOE DISPOSAL CELLS

Waste disposal facilities recently were designed at three other DOE sites near the PGDP: the Fernald site in Ohio, the Oak Ridge Reservation in Tennessee, and the Weldon Spring site in Missouri. Seismic events were considered in the design of each of these facilities. The CERCLA waste disposal facility at Fernald was designed with a peak ground acceleration of 0.13 g (GEOSYNTEC 1997). The CERCLA waste disposal facility at Weldon Spring was designed for a peak ground acceleration of 0.26 g (MKES 1993). The CERCLA waste disposal facility at Oak Ridge was designed for a peak ground acceleration of 0.22 g (Jacobs 1998). The Paducah reservation lies in an area of greater risk from earthquakes than any of the Fernald, Oak Ridge, or Weldon Spring sites and would have to be designed for a peak horizontal ground acceleration of at least 0.4 g. The seismic design for the possible PGDP waste disposal facility also is higher than the seismic design basis for the DOE CERCLA waste disposal facilities located at Hanford and at Idaho National Engineering and Environmental Laboratory.

4.8 NON-DOE FACILITIES

Hazardous waste disposal facilities have been located in seismic hazard zones equal to or higher than the PGDP site. A map (McCoy and Associates, Inc. 1992) showing the locations for 23 commercial hazard waste disposal facilities in the continental United States was superimposed on a Uniform Building

Code seismic hazard map (LMES 1995). This superposition showed that 4 out of 23 of the commercial sites were in equivalent or higher seismic risk zones than the PGDP.

4.9 PERFORMANCE OF LANDFILLS DURING EARTHQUAKES

Disposal facilities routinely are constructed in areas with comparable or greater seismic hazard than at the PGDP. The following paragraph is extracted from the EPA seismic design guidelines for municipal landfills (EPA 1995).

> In general, MSW landfills have performed extremely well in earthquakes. Observations of the performance of solid waste landfills subject to strong ground motions (Anderson and Kavazanjian, 1995; Matasovic, et al., 1995) indicate that minor cracking of cover soils at the waste/natural ground interface and disruption of landfill gas control systems due to loss of power and breaking of vertical wells and headers are the most common types of damage experience by MSW landfills subject to strong ground shaking. Neither of these effects is considered to present a significant environmental hazard. However, experience with the performance of modern landfills conforming to Subtitle D requirements is limited. Of the three landfills designed in accordance with Subtitle D standards subject to the strongest shaking in the Northridge, California earthquake of 17 January 1994, one experienced two tears in the liner, one of which was approximately 75 ft (23 m) in length, along an anchor trench above the waste. To date no landfill with a geosynthetic cover is known to have experienced fault displacement or liquefaction in the foundation during an earthquake (even though there are solid waste landfills known to be sited on active faults and liquefiable soils). Therefore, caution is warranted in concluding unconditionally that landfills will continue to perform well in earthquakes and investigations and analyses are required to demonstrate that disposal facilities are properly sited to avoid active faults and are properly designed to resist the effects of strong ground motions and liquefaction.

4.9.1 Loma Prieta Earthquake

On October 17, 1989, a strong earthquake (M_L = 7.1) occurred in the Santa Cruz Mountains in California. The epicenter was located to the north of Watsonville, California, and east of Santa Cruz, California. The earthquake was felt as far away as Los Angeles [560 km (350 miles)]. The earthquake heavily damaged many buildings and roads in the San Francisco and Monterey Bay regions. Utility services, including gas and electricity, were disrupted over a wide area and for an extended period of time (Orr and Finch 1990).

Several investigations of the performance of landfills in reaction to the earthquake have been reported. Orr and Finch (1990) reported on the damage experienced at several landfills near the epicenter. Johnson et al. (1991) reported on an assessment of the stability of the landfill slopes with regard to the maximum horizontal ground acceleration and made some conclusions regarding the excellent performance of the slopes. Sharma and Goyal (1991) reported on a comparison of observed and recorded field behavior with the results of available analysis techniques for a hazardous waste and sanitary landfill. Buranek and Prasad (1991) reported on a comparison of the observed and predicted deformations of a landfill.

Orr and Finch (1990) reported on the inspection of 10 solid waste landfills located near the epicenter of the earthquake. The most common type of damage was minor cracking of landfill slope surfaces with no failure of any landfill slopes. The estimated peak on-site horizontal acceleration varied from 0.10 g to

0.45 g based on the distance from the epicenter. Underground structures were not examined in this study, but facility operators reported no changes in quantities of leachate collected.

Johnson et al. (1991) reported that there were no slope failures even with relatively high slopes ranging up to 76 m (250 ft) with slope inclinations as steep as 2:1. They observed that the cracking experienced at the landfills was limited to areas where a contact between dissimilar materials existed or there were changes in geometry, such as benches. They concluded that several factors contributed to the excellent performance. These factors were as follows.

- Damping of ground motions by the "loose" waste where the waste is composed of a heterogeneous mixture of materials with a density ranging between 25 and 75 pounds per cubic foot. The damping or absorption or dissipation of energy at, or near, the interface between the natural and fill materials can effectively reduce the vertical and lateral forces reaching the landfill slope face.

- The strength of waste cannot be determined by conventional soil testing techniques due to the variability of materials. The authors surmised that relatively high-strength materials are randomly interwoven with less strong materials, which probably resulted in a reinforced structure beneath the outer soil layer, performing much as a reinforced earth slope performs.

- The low density and heterogeneous nature of the waste fill apparently caused it to be very flexible. This flexibility results in movement during earthquake ground motion that does not result in significant permanent deformation, but is reflected as minor cracks in perimeter areas.

Sharma and Goyal (1991) reported on an assessment of a hazardous waste and sanitary landfill for the effect of the earthquake and then compared the results with field data and observations. The Contra Costa Sanitary Landfill was analyzed for peak horizontal ground acceleration up through the waste, samples were evaluated for liquefaction potential and settlement, slopes were analyzed for stability, and deformations evaluated. Instrumentation installed about a year before the Loma Prieta earthquake allowed for verification of the results of the above evaluations and analyses.

- The peak horizontal ground accelerations were found to amplify through the waste up to a depth of about 15 m (50 ft); but above that height, the accelerations attenuated up to the crest of the waste. The shear wave velocity and unit weight of the waste did not significantly affect the peak acceleration profile in the refuse.

- The results of the evaluation of potential liquefaction indicated that layers of sand in the foundation materials would likely liquefy but that the volumetric strains would not exceed 3.75 cm (1.5 inches). This was in agreement with the fact that no liquefaction-induced damage was identified during the field observations.

- Static and seismic slope stability analyses, performed at the critical sections of Class I (hazardous) and Class II (sanitary) areas, indicated some potential for plastic deformation [a maximum of 7.5 cm (3 inches)] for calculated average accelerations. The estimated deformations correlate fairly well with negligible small deformation monitored in slope indicator casings.

Buranek and Prasad (1991) compared the observed deformation performance with predicted seismic deformation performance for six landfills near the epicenter. They concluded that the Makdisi and Seed simplified procedure for predicting permanent displacements appears to be an appropriate tool, but that considerable engineering judgment is needed in evaluating the analysis. In addition, the attenuation relationship used in the analyses provided a better comparison when the site was greater than 32 km

(20 miles) from the epicenter. The authors also concluded that better data on the static and dynamic stress-strain properties of landfill materials is needed.

4.9.2 Northridge Earthquake

A M_L = 6.7 earthquake (Northridge Earthquake) occurred northwest of Los Angeles, California, on January 17, 1994. Augello et al. (1995) reported on the investigation of 22 landfills within 100 km (62 miles) of the epicenter. Overall, the performance of landfills during the earthquake was found to be good. None of the surveyed landfills showed any signs of major damage. However, one of the geosynthetic-liner systems experienced significant damage as a result of two tears observed in the geosynthetic liner system. One tear was approximately 4 m (13 ft) long and 23 cm (9 inches) wide, and the other tear was 23 m (75 ft) long and 3 cm (1.2 inches) wide. It was hypothesized that the geomembrane tears were caused by the limited down-slope movement [30 cm (12 inches)] of the waste fill along the geosynthetic-lines back slope. In both cases, the tears were above the level of the waste and were repairable. No disruption of the low-permeability soil liner beneath the geomembrane was reported. Furthermore, no indication of disruption to the containment system below the top of the waste was reported.

5. CONCLUSIONS

Based on information reviewed to date, it would be possible to design, construct, operate, and close a potential on-site CERCLA waste disposal facility at PGDP that would satisfactorily address issues related to seismic hazard. Due to its proximity to the NMSZ, the PGDP is located in a "Seismic Impact Zone" as defined by state and federal regulations. Primary siting considerations will be to locate the potential on-site CERCLA waste disposal facility at least 61 m (200 ft) from any faults with Holocene Epoch-movement and away from soils with liquefaction potential. Commonwealth and federal regulations will require a seismic design coefficient of at least 0.40 g, which corresponds to the 2500-year earthquake event.

Although the seismic hazard for the PGDP is greater than for other DOE CERCLA waste disposal facilities, established design and construction methods can adequately mitigate the increased hazard. Therefore, based on information reviewed to date, seismic hazard should not be considered a barrier to the construction of a potential on-site CERCLA waste disposal facility at PGDP.

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7. REPORT AUTHORSHIP

This Technical Memorandum report was prepared for DOE by Science Applications International Corporation under contract to Bechtel Jacobs Company LLC. The qualifications of the two primary authors of the report include a Ph.D. in Geophysics, B.S. and M.S. degrees in Civil Engineering, and Professional Geologist and Professional Engineer certifications. Both primary authors have more than 20 years experience in seismic characterization and design studies for major facilities.

Appendix A

COMMONWEALTH OF KENTUCKY REGULATIONS

Table A.1. Potential state seismic considerations for siting design of an on-site CERCLA waste disposal facility

Commonwealth of Kentucky Citation	Requirement	Summary
401 KAR Chapter 34 – Standards for Owners and Operators of Hazardous Waste Storage, Treatment, and Disposal Facilities		
401 KAR 34:020 – General Facility Standards	Section 9 – Location Standards "(1) Seismic considerations. Portions of new facilities where treatment, storage, or disposal of hazardous waste will be conducted shall not be located within 61 meters (approximately 200 feet) of a fault which had displacement in Holocene time."	Hazardous waste cells must not be closer than 200 ft to a fault that had displacement in Holocene time.
401 KAR 34:340 – Appendix on political jurisdictions and demonstration of compliance with the seismic standards.	"…This chapter establishes minimum standards for new hazardous waste sites or facilities. This administrative regulation identifies those counties which must have compliance with the seismic standards demonstrated before siting a hazardous waste site or facility." "Section 1. Political Jurisdictions in which Compliance with Section 9(1) of 401 KAR 34:020 Must be Demonstrated. If the proposed hazardous waste site or facility is within one (1) of the following counties, compliance with Section 9(1) of 401 KAR 34:020 must be demonstrated unless the cabinet has issued a variance pursuant to 401 KAR 30:020, Section 2."	McCracken and Ballard counties are included within the list cited.
401 KAR Chapter 38 – Hazardous Waste Permitting Process		
401 KAR 38:090 – General Contents of Part B Application (N.B.; potential ARARs would involve compliance with only the substantive portions of this section)	"(11) Facility location information: "(a) In order to determine the applicability of the seismic standard, Section 9(1) of 401 KAR 34:020, the owner or operator of a new facility shall identify the political jurisdiction (county, township, or election district) in which the facility is proposed to be located.	McCracken County
	"(b) If the facility is proposed to be located in an area listed in 401 KAR 34:340 the owner or operator shall demonstrate compliance with the seismic standard. This demonstration may be made using either published geologic data or data obtained from field investigations carried out by the applicant. The information provided shall be of such quality to be acceptable to geologists experienced in identifying and evaluation seismic activity. The information submitted shall show that either:	McCracken County is on the list.

Table A.1. (continued)

Commonwealth of Kentucky Citation	Requirement	Summary
401 KAR 38:090 – General Contents of Part B Application (continued)	"1. No faults which have had displacement in Holocene time are present, or no lineations which suggest the presence of a fault (which have had displacement in Holocene time) within 3,000 feet of a facility are present, based on data from: "a. Published geologic studies; "b. Aerial reconnaissance of the area within a five (5) mile radius from the facility; "c. An analysis of aerial photographs covering a 3,000 foot radius of the facility; and "d. If needed to clarify the above data, a reconnaissance based on walking portions of the area within 3,000 feet of the facility; or	The location of faults that have moved since the start of the Holocene time shall be identified and used as a criterion in siting a potential on-site CERCLA waste disposal facility.
	"2. If faults (to include lineations) which have had displacement in Holocene time are present within 3,000 feet of a facility, no faults pass within 200 feet of the portions of the facility where treatment, storage, or disposal of hazardous waste will be conducted, based on data from a comprehensive geologic analysis of the site. Unless a site analysis is otherwise conclusive concerning the absence of faults within 200 feet of such portions of the facility, data shall be obtained from a subsurface exploration (trenching) of the area within a distance no less than 200 feet from portions of the facility where treatment, storage or disposal of hazardous waste will be conducted. Such trenching shall be performed in a direction that is perpendicular to known faults (which have had displacement in Holocene time) passing within 3,000 feet of the portions of the facility where treatment, storage, or disposal of hazardous waste shall be conducted. Such investigation shall document with supporting maps and other analyses the location of any faults found."	The location of faults that have moved since the start of the Holocene time shall be identified and used as a criterion in siting a potential on-site CERCLA waste disposal facility.
401 KAR Chapter 48 – Standards for Solid Waste Facilities		
401 KAR 48:050 – Siting requirements for solid waste landfills.	Section 5. Fault Areas. "Waste cells of a solid waste landfill shall not be located within 200 ft of a fault that has had displacement in Holocene time."	Solid waste cells must not be closer than 200 feet to a fault that had displacement in Holocene time.
401 KAR 48:070 – Design requirements for contained landfills	"Section 3. Seismic Impact Zones. At a new contained solid waste landfill unit located in a seismic impact zone, all containment structures, including liners, leachate collection systems, and surface water control systems shall be designed to resist the maximum anticipated horizontal acceleration in lithified material for the site."	All components shall be designed for the defined maximum horizontal acceleration.

Table A.1. (continued)

Commonwealth of Kentucky Citation	Requirement	Summary
	902 KAR Chapter 100 – Radiology	
902 KAR 100:022 – Licensing requirements for land disposal of radioactive waste	"Section 22 – Disposal Site Suitability Requirements for Land Disposal. Disposal site suitability for near-surface disposal. The following are the minimum characteristics a disposal site shall have to be acceptable for use as a near-surface disposal facility: … "(9) Areas shall be avoided if tectonic processes such as faulting, folding, seismic activity, or vulcanism may occur with a frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives of this administrative regulation, or may preclude defensible modeling and prediction of long-term impacts."	Areas of faulting, folding, seismic activity, or vulcanism should be avoided as part of the site selection procedure.

Appendix B

FEDERAL (NON-DOE) REGULATIONS

Table B.1. Potential Federal (Non-DOE) Seismic Considerations for Siting and Design of an On-site CERCLA Waste Disposal Facility

Federal (Non-DOE) Citation	Requirement	Summary
	10 CFR Part 61 – Licensing requirements for land disposal of radioactive waste	
10 *CFR* 61.50 – Disposal site suitability requirements for land disposal	"(9) Areas must be avoided where tectonic processes such as faulting, folding, seismic activity, or vulcanism may occur with such frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives of subpart C of this part, or may preclude defensible modeling and prediction of long-term impacts."	Areas of faulting, folding, seismic activity, or vulcanism should be avoided as part of the site selection procedure.
	40 CFR Part 258 – Criteria for Municipal Solid Waste Landfills	
40 *CFR* 258.13 – Fault areas	"(a) New MSWLF units and lateral expansions shall not be located within 200 feet (60 meters) of a fault that has had displacement in Holocene time unless the owner or operator demonstrates to the Director of an approved State that an alternative setback distance of less than 200 feet (60 meters) will prevent damage to the structural integrity of the MSWLF unit and will be protective of human health and the environment. "(b) For the purposes of this section: "(1) Fault means a fracture or a zone of fractures in any material along which strata on one side have been displaced with respect to that on the other side. "(2) Displacement means the relative movement of any two sides of a fault measured in any direction. "(3) Holocene means the most recent epoch of the Quaternary period, extending from the end of the Pleistocene Epoch to the present."	Hazardous waste cells should not be closer than 200 ft to a fault that had displacement in Holocene time.
40 *CFR* 258.14 – Seismic impact zones	"(a) New MSWLF units and lateral expansions shall not be located in seismic impact zones, unless the owner or operator demonstrates to the Director of an approved State/Tribe that all containment structures, including liners, leachate collection systems, and surface water control systems, are designed to resist the maximum horizontal acceleration in lithified earth material for the site. The owner or operator must place the demonstration in the operating record and notify the State Director that it has been placed in the operating record. "(b) For the purposes of this section: "(1) Seismic impact zone means an area with a ten percent or greater probability that the maximum horizontal acceleration in lithified earth material, expressed as a percentage of the earth's gravitational pull (g), will exceed 0.10g in 250 years. "(2) Maximum horizontal acceleration in lithified earth material means the maximum expected horizontal acceleration depicted on a seismic hazard map, with a 90 percent or greater probability that the acceleration will not be exceeded in 250 years, or the maximum expected horizontal acceleration based on a site-specific seismic risk assessment.	All components shall be designed for the defined maximum horizontal acceleration.

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Table B.1. (continued)

Federal (Non-DOE) Citation	Requirement	Summary
40 *CFR* 258.14 – Seismic impact zones (continued)	"(3) Lithified earth material means all rock, including all naturally occurring and naturally formed aggregates or masses of minerals or small particles of older rock that formed by crystallization of magma or by induration of loose sediments. This term does not include man-made materials, such as fill, concrete, and asphalt, or unconsolidated earth materials, soil, or regolith lying at or near the earth surface."	
40 CFR Part 264 – Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities		
40 *CFR* 264.18 – Location standards	"(a) Seismic considerations. "(1) Portions of new facilities where treatment, storage, or disposal of hazardous waste will be conducted must not be located within 61 meters (200 feet) of a fault which has had displacement in Holocene time. "(2) As used in paragraph (a)(1) of this section: "(i) 'Fault' means a fracture along which rocks on one side have been displaced with respect to those on the other side. "(ii) 'Displacement' means the relative movement of any two sides of a fault measured in any direction. "(iii) 'Holocene' means the most recent epoch of the Quarternary period, extending from the end of the Pleistocene to the present.	Hazardous waste cells should not be closer than 200 ft to a fault that had displacement in Holocene time.
	"[Comment: Procedures for demonstrating compliance with this standard in part B of the permit application are specified in Sec. 270.14(b)(11). Facilities which are located in political jurisdictions other than those listed in appendix VI of this part, are assumed to be in compliance with this requirement.]"	
40 CFR 270 EPA – Administered Permit Program: The Hazardous Waste Permit Program		
40 *CFR* 270.14(b)(11) – Contents of part B [permit applications]: General requirements (as referenced in 40 *CFR* 264.18) (N.B., potential ARARs would involve compliance with only the substantive portions of this section)	"(11) Facility location information; "(i) In order to determine the applicability of the seismic standard [Sec. 264.18(a)] the owner or operator of a new facility must identify the political jurisdiction (e.g., county, township, or election district) in which the facility is proposed to be located.	McCracken County

Table B.1. (continued)

Federal (Non-DOE) Citation	Requirement	Summary
40 *CFR* 270.14(b)(11) – Contents of part B [permit applications]: General requirements (as referenced in 40 *CFR* 264.18) (continued)	"(ii) If the facility is proposed to be located in an area listed in appendix VI of part 264, the owner or operator shall demonstrate compliance with the seismic standard. This demonstration may be made using either published geologic data or data obtained from field investigations carried out by the applicant. The information provided must be of such quality to be acceptable to geologists experienced in identifying and evaluating seismic activity. The information submitted must show that either: "(A) No faults which have had displacement in Holocene time are present, or no lineations which suggest the presence of a fault (which have displacement in Holocene time) within 3,000 feet of a facility are present, based on data from: "(1) Published geologic studies, "(2) Aerial reconnaissance of the area within a five-mile radius from the facility. "(3) An analysis of aerial photographs covering a 3,000 foot radius of the facility, and "(4) If needed to clarify the above data, a reconnaissance based on walking portions of the area within 3,000 feet of the facility, or "(B) If faults (to include lineations) which have had displacement in Holocene time are present within 3,000 feet of a facility, no faults pass with 200 feet of the portions of the facility where treatment, storage, or disposal of hazardous waste will be conducted, based on data from a comprehensive geologic analysis of the site. Unless a site analysis is otherwise conclusive concerning the absence of faults within 200 feet of such portions of the facility, data shall be obtained from a subsurface exploration (trenching) of the area within a distance no less than 200 feet from portions of the facility where treatment, storage, or disposal of hazardous waste will be conducted. Such trenching shall be performed in a direction that is perpendicular to known faults (which have had displacement in Holocene time) passing within 3,000 feet of the portions of the facility where treatment, storage, or disposal of hazardous waste will be conducted. Such investigation shall document with supporting maps and other analyses, the location of faults found.	Appendix VI does not include any part of KY. Defer to requirement in 401 KAR 38:090.
	"[Comment: The Guidance Manual for the Location Standards provides greater detail on the content of each type of seismic investigation and the appropriate conditions under which each approach or a combination of approaches would be used.]"	
	Note that Appendix VI to Part 264 – Political jurisdictions in which compliance with §264.18(A) must be demonstrated, as referenced in 40 *CFR* 270.14(b)(11), does not include any portion of Kentucky, nor does it include any portions of Missouri, Tennessee, or Illinois.	
EPA Guidance	*RCRA Subtitle D (258) Seismic Design Guidance for Municipal Solid Waste Landfill Facilities* (EPA/600/R-95/051 dated April 1995)	Provides the guidance for implementation of 40 *CFR* 258.

Table B.1. (continued)

Federal (Non-DOE) Citation	Requirement	Summary
NRC NUREG-1573	Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities	The siting requirements under 10 *CFR* 61.50 should be followed in siting a facility.

Appendix C

DOE ORDERS AND STANDARDS

Table C.1. Potential Federal (DOE) Seismic Considerations for Siting and Design of an On-site CERCLA Waste Disposal Facility

DOE Order Citation	Requirement	Summary
	Orders	
DOE O 420.1	Facility Safety	Establishes applicability to DOE Elements responsible for DOE-owned/leased facilities
• Section 4.4	Natural Phenomena Hazards Mitigation "The objectives of this section are to ensure that all DOE facilities are designed, constructed, and operated so that the general public, workers, and the environment are protected from the impact of Natural Phenomena Hazards (NPHs). The provisions of this section apply to DOE sites and facilities. The provisions of this section cover all natural phenomena hazards such as seismic, wind, flood, [and] lightning. Where no specific requirements are specified, model building codes or national consensus industry standards shall be used."	The natural phenomenon of seismic activity must be considered in siting and design.
• Section 4.4.1	General Requirements "For hazardous facilities, safety analyses shall include the ability of Systems, Structures, Components (SSCs) and personnel to perform their intended safety functions under the effects of natural phenomena."	Safety analysis must include the effects of seismic events.
• Section 4.4.2	Natural Phenomena Mitigation Design Requirements "Systems, structures and components shall be designed, constructed and operated to withstand the effects of natural phenomena as necessary to ensure the confinement of hazardous material, the operation of essential facilities, the protection of government property, and the protection of life safety for occupants of DOE buildings. The design process shall consider potential damage and failure of systems, structures and components due to both direct and indirect natural phenomena effects, including common cause effects and interactions from failures of other systems, structures and components. Furthermore, the seismic requirements of Executive Order 12699 shall be addressed." "Systems, structures and components for new DOE facilities, and additions or major modifications to existing systems, structures and components shall be designed, constructed and operated to meet the requirements in the previous paragraph. Any additions and modifications to existing DOE facilities shall not degrade the performance of existing systems, structures and components to the extent that the objectives in this Section cannot be achieved under the effects of natural phenomena."	Design, construction, and operations shall be performed to ensure the containment of hazardous material.

Table C.1. (continued)

DOE Order Citation	Requirement	Summary
• Section 4.4.4	Natural Phenomena Hazards Assessment "The design and evaluation of facilities to withstand natural phenomena shall be based on an assessment of the likelihood of future natural phenomena occurrences. The natural phenomena hazards assessment shall be conducted commensurate with a graded approach and commensurate with the potential hazard of the facility." "For new Sites; natural phenomena hazards assessment shall be conducted commensurate with a graded approach to the facility. Site planning shall consider the consequences of all types of natural phenomena hazards." "For existing Sites; if there are significant changes in natural phenomena hazards assessment methodology or site-specific information, the natural phenomena hazards assessments shall be reviewed and shall be updated, as necessary. A review of the natural phenomena hazards assessment shall be conducted at least every 10 years. The review shall include recommendations to DOE on the need for updating the existing natural phenomena hazards assessments based on identification of any significant changes in methods or data."	An assessment of seismic hazard should be conducted in the siting and design of a potential on-site CERCLA waste disposal facility.
• Section 4.4.5	Natural Phenomena Detection "Facilities or sites with hazardous materials shall have instrumentation or other means to detect and record the occurrence and severity of seismic events."	Instrumentation shall be available to monitor seismic events.
• Section 4.4.6	Post-Natural Phenomena Procedures "Facilities or sites with hazardous materials shall have procedures that include, inspecting the facility for damage caused by severe natural phenomena, and placing the facility into a safe configuration when such damage has occurred."	Procedures for inspection following a severe seismic event shall be in place.
Technical Standard		
DOE-STD-1020-94	Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities	Standard provides criteria for design of new SSCs and for evaluation, modification, or upgrade of existing SSCs so that DOE facilities safely withstand the effects of seismic events.
DOE-STD-1021-93	Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems, and Components	Provides design and evaluation guidelines for selecting performance categories of SSCs.
DOE-STD-1022	Natural Phenomena Hazards Characterization Criteria	Standard for studies of site characteristics.

9h

Table C.1. (continued)

DOE Order Citation	Requirement	Summary
DOE-STD-1023	Natural Phenomena Hazards Assessment Criteria	Standard provides criteria for hazard assessment to ensure that adequate design basis load levels are established.
DOE-STD-1024-92	Guidelines for Use of Probabilistic Seismic Hazard Curves at Department of Energy Sites for Department of Energy Facilities	Standard provides requirements for developing seismic hazard curves.
	Citations	
ES/CNPE-95/2	Seismic Hazard Criteria for the Oak Ridge, Tennessee, Paducah, Kentucky, and Portsmouth, Ohio, U.S. Department of Energy Reservations	Developed a seismic hazard criteria with a mean peak ground acceleration of 0.35g (horizontal) and 0.24g (vertical).

DOE- PAD-99-0065

AUG 17 2000

JAMES E. BICKFORD
SECRETARY

PAUL E. PATTON
GOVERNOR

COMMONWEALTH OF KENTUCKY
NATURAL RESOURCES AND ENVIRONMENTAL PROTECTION CABINET
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August 14, 2000

Assigned to J. Shindula
Due Date: 9/27/00

cc: Document Center
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Mr. Don Seaborg, Site Manager
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Paducah Site Office
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Mr. Gordon Dover, Plant Manager
Bechtel Jacobs Company /LLC
761 Veterans Avenue
Kevil, Kentucky 42053

RE: *Initial Assessment of Consideration of On-site Disposal of Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) Waste as a Potential Disposal Option at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky, DOE/OR/07-1893&D1*
Paducah Gaseous Diffusion Plant
Paducah, McCracken County, Kentucky
EPA ID# KY8-890-008-982

Gentlemen:

The Division of Waste Management has reviewed the referenced document submitted July 10, 2000. This document was submitted in response to our letter dated February 23, 2000, which requested an analysis of the siting restrictions which might prevent Department of Energy (DOE) from placing a CERCLA cell at the Paducah Gaseous Diffusion Plant. The assessment was to address "seismic, floodplain, characterization and geologic considerations." Although these issues were discussed, the information provided was not adequate to make a determination on whether there are any siting issues that would warrant terminating any further consideration of building the CERCLA cell. Based upon the Division's initial review of the sitting criteria, we believe there is sufficient justification to proceed with the development of a Feasbility Study.

The seismic issues, especially those related to the New Madrid Seismic Zone, are of particular concern. In regard to the seismic issue, the Feasibity Study should identify any relevant paleoseismic features in the West Paducah/Kevil area that would reveal the extent of liquefaction features related to past seismic events. Likewise, the Feasibility Study should address the currently accepted recurrence intervals for earthquakes in the region of magnitude 6 or greater, with special consideration given to site specific amplification effects that may be produced by such events.

It is recommended that an expedited seismic analysis should be undertaken immediately to determine if this site is suitable for placement of the proposed CERCLA cell. To facilitate a better understanding on the seismic issues, it is recommended that our staff and the DOE staff continue to exchange information prior to the submittal of the D1 Feasibility Study. Furthermore, it is recommended that a meeting or conference call be held within approximately 45 days of receipt of this letter for staff involved in evaluating the seismic issues. In the development of the Feasibility Study the attached comments on the initial assessment should be taken into consideration. If you have any questions, please direct them to Linda Goodwin Martin or Brian Baker at 502/564-6716.

Sincerely,

Michael V. Welch, P.E., Manager
Hazardous Waste Branch

Attachment
LGM/TT/bb

cc: Carl Frode Jr., EPA Region IV
Robert Sleeman, ORR/DOE
John Morgan/Bechtel-Jacobs, Co.
John Shepard, PGDP/DOE
Margie Williams, KDWM-Paducah
Gaye Brewer, Hazardous Waste, Paducah Site Office
John Volpe, CHS
Jim Lane, Fish and Wildlife
Tuss Taylor/Brian Baker/Linda Martin/Dale Burton, Hazardous Waste

General Comments

1. The Paducah Gaseous Diffusion Plant in located in a region affected by the New Madrid Seismic Zone as well as other fault zones that have experienced recent seismic activity. The Center for Earthquake Research and Information (CERI) in Memphis located 4,387 seismic events in the New Madrid region between 1974 and 1998, many of which were in the immediate vicinity of the PGDP. The U.S. Geological Survey CERI's Web page has a computed set of probabilities that estimate the potential for different magnitude earthquakes to occur in the New Madrid seismic zone. Their data predicts that a magnitude 6.3 event will occur every 70 years (plus or minus 15 years) and that an 8.3 event will occur every 550 years (plus or minus 125 years). It is recommended that the initial design for the CERCLA cell take into consideration the predicted regional seismic events for the next 1000 years.

2. The U.S. Geological Survey has constructed peak acceleration maps which include the Paducah region. These resources should be reviewed when developing the Feasibility Study. As you indicate, it is expected that a CERCLA cell for this site would need to be designed more conservatively than existing PGDP landfills.

3. The applicable federal and state regulations which deal with siting such a landfill will need to be followed. These include but are not limited to: 40 CFR 258.17, 40 CFR 258.14, 40 CFR 258.15, 401 KAR 38:090, Section 2(11), along with other ARARs. These design standards will have to be met as a minimum standard.

4. In evaluating the off-site disposal option, it is recommended that this include consideration for any other potential sites where the CERCLA cell could be constructed.

5. For your information, an attachment is included that identifies certain references that may be of use when evaluating the seismic issues.

Specific Comments

1. **Section 1, third paragraph, page 1** - It is stated that the Oak Ridge Reservation, the Fernald Environmental Management Project, and the Weldon Springs Site Remedial Action Project share similar hydrologic conditions and were used for comparative evaluation in the initial assessment. Our staff believes that there are significant differences with these sites in regard to the hydrogeologic settings relative to the Paducah site. Among other details, the depth to bedrock at the Weldon Springs site is modest relative to Paducah and there are significant differences in the nature of the unconsolidated materials. With the Fernald site, the seismic issues are much less of a

concern. Nevertheless, the Division agrees that knowledge obtained at these sites will be of significant value in developing a design for the Paducah site.

2. **Section 6.0 Major Considerations, page 15**

6.1 Costs - The hydrogeologic and seismic issues at the PGDP could result in significantly higher costs than were incurred at the Oak Ridge, Fernald, and Weldon Springs sites.

6.3 Reliability of Disposal Outlets - While the Division does agree with the general concepts stated in this section, if the long-term evaluation considers the potential for an earthquake at the PGDP, then this reliance becomes questionable.

6.7 Stakeholder Acceptance - Based upon initial reactions, as expressed in the July 20, 2000 SSAB meeting (when this initial assessment was presented), the seismic issue will likely be of special concern with the local community.

6.8 Schedule - The schedule will need to allow for an extensive site-specific seismic evaluation and a potentially elaborate slope stability design.

ATTACHMENT

A Partial List of References for Consideration of Seismic Issues

Seismic Hazard Evaluation for the Paducah Gaseous Diffusion Plant, Paducah KY. Report K/GDP/SAR/Sub-1, Rev 1, Jan. 1993. Contractor: Risk Engineering.

Site-Specific Earthquake Response Analysis of the Paducah Gaseous Diffusion Plant, Paducah KY. Report MPGL-93-14, Aug 1993. Contractor: Risk Engineering

Reassessment of Liquefaction Potential and Estimates of Earthquake Induced Settlement at the Paducah, KY Gaseous Diffusion Plant. Report GL-96-6, April 1996. Contractor: Army Corps of Engineers

Updated Probabilistic Seismic Hazard Analysis for the Paducah Gaseous Diffusion Plant, Paducah, KY. Final Report of Contract USEC-96-C-001. Contractor: Risk Engineering.

Assessment and Interpretation of Cross-and Down-Hole Seismograms at the Paducah Gaseous Diffusion Plant. Report K/GDP/SAR-9, 1991. Contractor: Martin Marietta Energy Systems, Inc., Authors: W.P. Staub, J.C. Wang, and R.J. Selfridge.

Evaluation of Seismic Hazard at the Paducah Gaseous Diffusion Plant, Professional Paper from the Third DOE Natural Phenomena Hazards Mitigation Conference, 1991, Contractor: Risk Engineering (Toro and McGuire).

Report to Risk Engineering PSHA, submitted September 1997 (Van Arsdale and Johnston)

Absence of Paleoliquefaction on Ohio River Sediments Along the Indiana-Kentucky Border and the Illinois-Kentucky Border, Contractor: Risk Engineering

Seismic Hazards of the Upper Mississippi Embayment. Report to the United States Army Corps of Engineers, 1999, Van Arsdale.

The New Madrid Earthquakes: An Engineering - Geologic Interpretation of Relict Liquefaction Features, USGS, S. F. Obermeir.

Site Amplification of Site Ground Motion in the Paducah, Kentucky Area, 1992, Dissertation by J. B. Harris

Acquisition of SH-Wave Seismic Reflection and Refraction Data in the Northeastward Trending Contamination Plume at the PGDP, 1998, C. Langston and R. Street.

RCRA Subtitle D (258) Seismic Design Guidance for Municipal Solid Waste Landfill Facilities, EPA

The above is not a complete list of applicable references. In addition to these particular documents and the resources available at CERI in Memphis, it is recommend that the resources at the Mid-America Earthquake Center in Urbana, IL be investigated.

AUG 2 1 2000

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RE: Initial Assessment of Consideration of On-Site Disposal of Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) Waste as a Potential Disposal Option at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky, DOE/OR/07-1893&D1.

Dear Sirs:

The Radiation Health and Toxic Agents Branch, Department for Public Health, Cabinet for Health Services has completed its review of DOE 's Initial Assessment of an on-site CERCLA CELL at the Paducah Gaseous Diffusion Plant (PGDP). Based on discussions with DOE and the information provided to date, the site will essentially be a low-level radioactive disposal site, which under most conditions would be required to meet stringent siting requirements.

The Cabinet for Health Services, as a U.S. Nuclear Regulatory Commission (NRC) Agreement State, has adopted in 902 KAR 100:021 and 902 KAR 100:022, specific requirements for the siting and disposal of low-level radioactive waste. Based on the requirements in 902 KAR 100:021 and 902 KAR 100:022, the Radiation Health and Toxic Agents Branch has a number of concerns regarding the disposal of low-level radioactive waste at the PGDP. In addition, the subject document leaves a significant number of critical unanswered questions.

The Radiation Health and Toxic Agents Branch feels conditions at PGDP exist that may deem the site inappropriate for the construction of a low-level radioactive waste disposal facility. These conditions are:

1) The site is located in a humid environment (high rainfall); and
2) The site is located on unconsolidated sediments in the vicinity of a major fault zone that has experienced major seismic activity within the last 150 years.

Furthermore, waste characteristics at PGDP may also deem the site inappropriate for disposal of low-level radioactive waste.

1) The majority of the radioactive waste at PGDP is most likely Class A waste that contains mainly long-lived radionuclides (^{99}Tc, U isotopes, Pu isotopes, etc.).
2) Because the radionuclides at PGDP are long-lived, it can be assumed that physical barriers cannot be designed to function long enough to influence, via radioactive decay, the long-lived radionuclide inventory available for release to groundwater and surface water.

In addition to the above, mixing of low-level radioactive waste and other types of waste would be considered inappropriate in a high rainfall environment. Bio-degradation of non-radioactive waste may lead to the mobilization of radionuclides in the waste. This would result in increased mobility of radionuclides and result in contamination of the aquifer and surface water.

The above issues raise serious concerns that must be evaluated by the DOE to ensure the long-term stability of a disposal cell. The Radiation Health and Toxic Agents Branch recommends that DOE utilize NRC's *"Branch Technical Position on a Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities,"* NUREG-1573 for assessment of a disposal cell at PGDP. Engineering technologies must be evaluated which address the concerns of the Radiation Health and Toxic Agents Branch.

Based on the construction of the CERCLA CELL at the Maxey Flats Nuclear Disposal Site and the record of oversight for the cell, the Radiation Health and Toxic Agents Branch does not feel the necessary CERCLA oversight and controls exist to ensure proper construction of a facility at PGDP. The Radiation Health and Toxic Agents Branch is concerned that loss of containment may lead to long-term radiochemical contamination of the aquifer and surface water with serious implications for public health.

In summary, the Radiation Health and Toxic Agents Branch could support the development of a Feasibility Study for a CERCLA CELL if certain critical issues were addressed in the document. These issues include:

1. Independent oversight contractors who have the approval of the Cabinet for Health Services, Department for Public Health, Radiation Health and Toxic Agents Branch.

2. Consideration of an organizational structure for oversight clearly establishing lines of reporting to both DOE and the Cabinet for Health Services for oversight.

3. Consideration of CHS having an equal voice in the oversight of the cell as setout by the requirements of 902 KAR 100:021 and 902 KAR 100:022.

4. The DOE considers providing adequate funding to the Cabinet for Health Services to conduct all necessary oversight activities.

If you or your staffs have questions regarding our position, feel free to contact me at (502) 564-7818 extension 3692 or by e-mail at john.volpe@mail.state.ky.us.

Sincerely,

John A. Volpe, Ph.D., Manager
Radiation Health and Toxic Agents Branch

c: David Klee, DPH
Carl Frode Jr., EPA Region IV
John Morgan/Bechtel Jacobs, Co.
Robert Daniell, NREPC
John Shepard, PGPD/DOE
Steve Hampson, UK

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Rcvd 14 August 2000

SUBJ: Initial Assessment of Consideration of On-Site Disposal of Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) Waste, as a Potential Disposal Option at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky
(DOE/OR/07-1893&D1)

Gentlemen:

The Environmental Protection Agency (EPA) has completed our review of the above cited document. Our review concludes that many sections of this document are insufficient to make a determination if this project should move forward. However, knowing that the next document (i.e., Remedial Investigation/Feasibility Study) will provide the details necessary to determine if this CERCLA disposal facility should be constructed and operated, EPA encourages the Department of Energy Paducah Gaseous Diffusion Plant to proceed in the development of the documentation to see if this facility can be justified and warrants construction.

If you have any questions regarding this matter, please contact me at (404) 562-8550.

Sincerely,

Carl R. Froede Jr.

Carl R. Froede Jr., P.G.
Federal Facilities Branch
Waste Management Division
U.S. EPA Region 4

cc: T. Taylor, KDEP/Frankfort
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